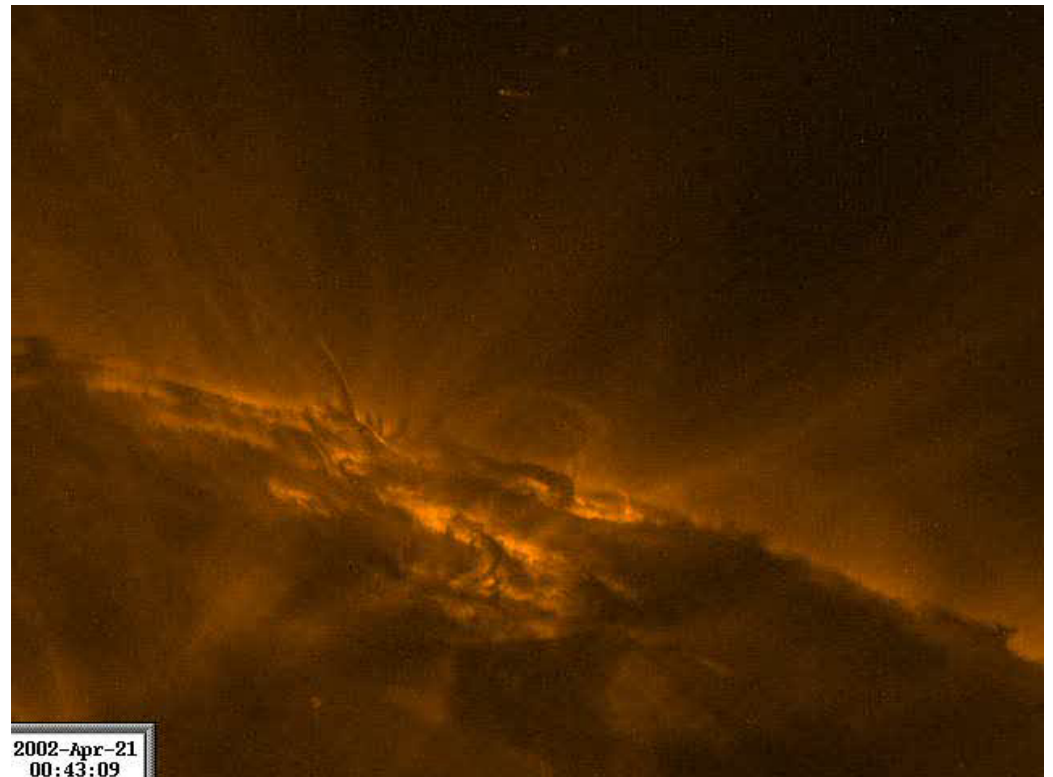
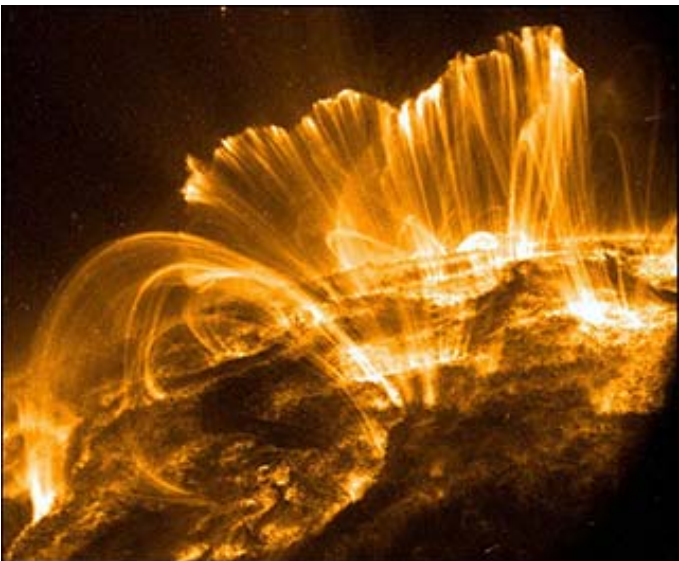
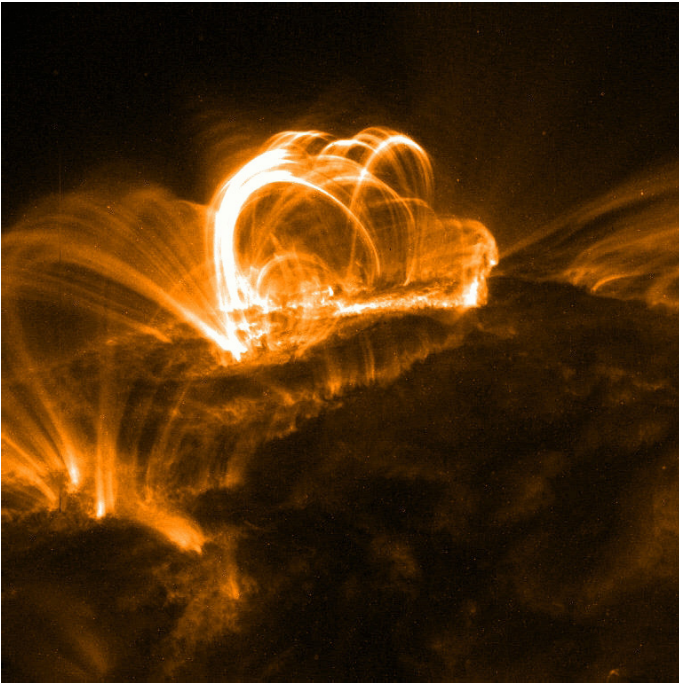


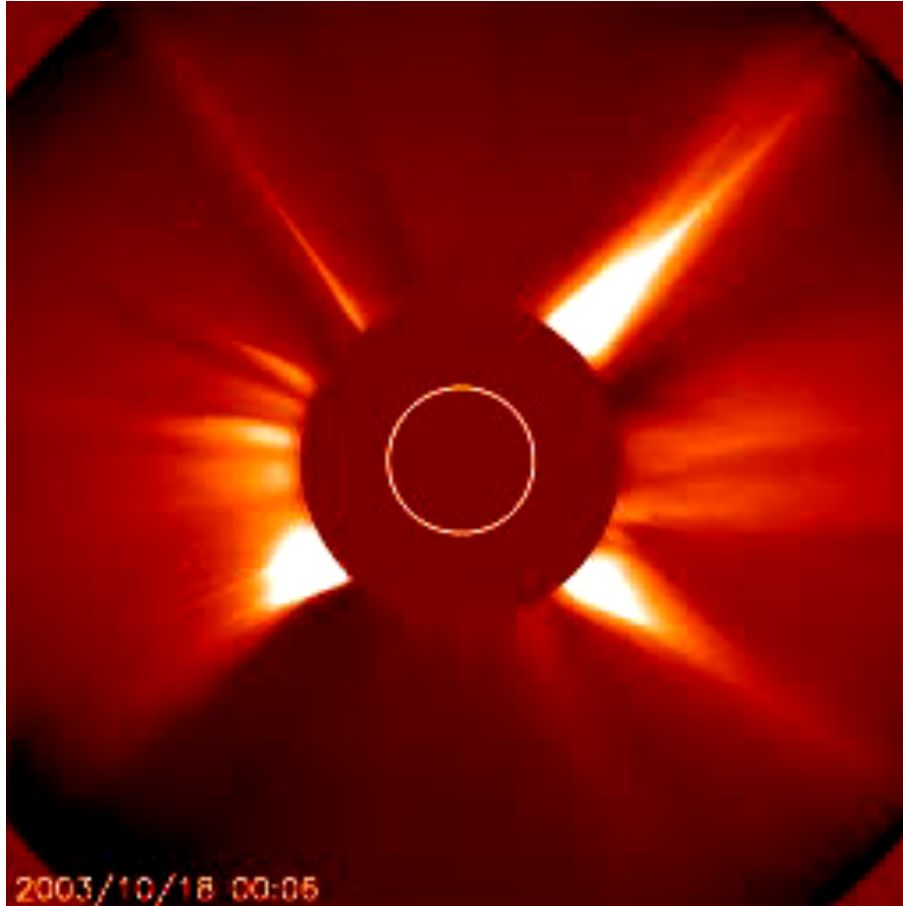
What do we not yet know about solar flares and solar energetic particles (SEPs)?

Richard Harrison
Head of Space Physics
RAL Space
Rutherford Appleton Laboratory





- Re-phrase the question: What do we not yet know about flares, and SEPs in the context of space weather?
- So, what is important? Events that produce impact: Energetic particles, CMEs at Earth, EM enhancements
- In particular, issues relevant to prediction (onsets, arrivals), and impact.



... at the heart of our question is the flare-CME relationship

1. The flare myth

- Gosling (1993, JGR, 98) stressed that the CME rather than the flare is the principal source of transient interplanetary activity.
- This followed work which disconnected the flare and CME onset (e.g. See review by Harrison, 1991, Phil. Trans R. Soc. Lond. A336 and refs. therein)
- Svestka (1995, Solar Phys. 160): Gosling's conclusion is 'faulty and dangerous.. It might deflect scientists attention from phenomena which are the most energetic events on the Sun'
- Svestka pointed to different flare classes – stating that 'all the important interplanetary and geophysical effects which Gosling ascribes to CMEs are – in the case that a flare is involved – associated with 'eruptive' flares'

1. The flare myth

The fact that various researchers sought to find different flare classes and also acknowledged that there were CMEs without flares should raise alarm bells

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Harrison, 1991, Phil.
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The fact that they may be
the most energetic events is
actually not relevant

- Svestka (1995, Solar Phys. 160): Gosling's conclusion is 'faulty and dangerous.. It might **deflect scientists attention from phenomena which are the most energetic events on the Sun**'
- Svestka pointed to **different flare classes** – stating that 'all the important interplanetary and geophysical effects which Gosling ascribes to CMEs are – **in the case that a flare is involved** – associated with 'eruptive' flares'

2. The flare-CME relationship

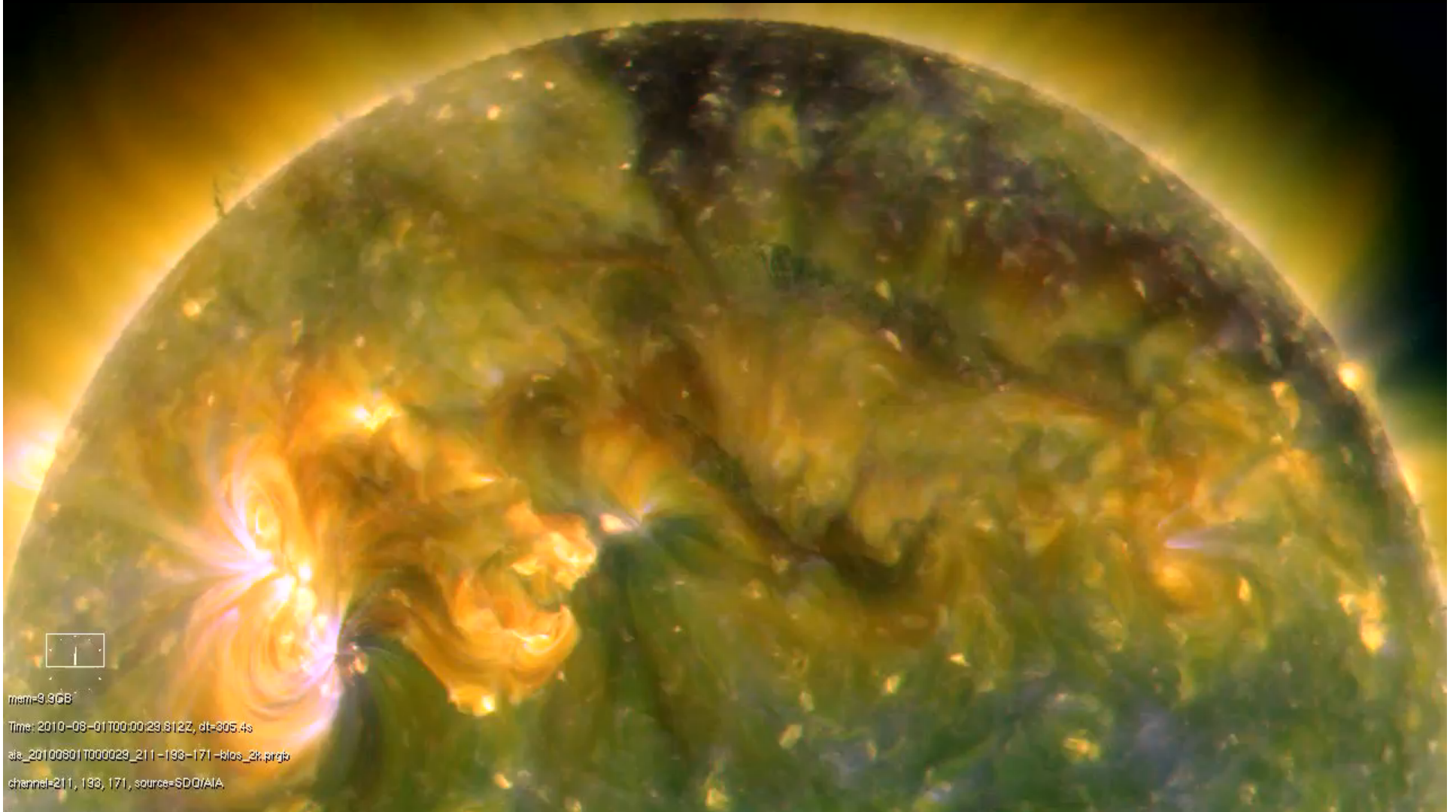
- Harrison (1995, A&A 304) – statistical study of CMEs & flares:
 - 151 CMEs
 - Strong association between CME onsets and flare onsets – 40% of CMEs had an associated flare, 11% of flares had an associated CME - i.e. many CMEs occur without flares
 - Flares associated with CMEs tend to be longer duration and brighter – but they can be of any duration and brightness
 - The flares can lie anywhere under the CME span (note different scale-sizes)
 - The relative timing between flare onset and CME onset can vary considerably, with either leading

The August 2010 Events

Schrijver and Title, 2011, JGR 116

Harrison et al., 2011, Astrophys. J., submitted

Möstl et al., 2011, in preparation

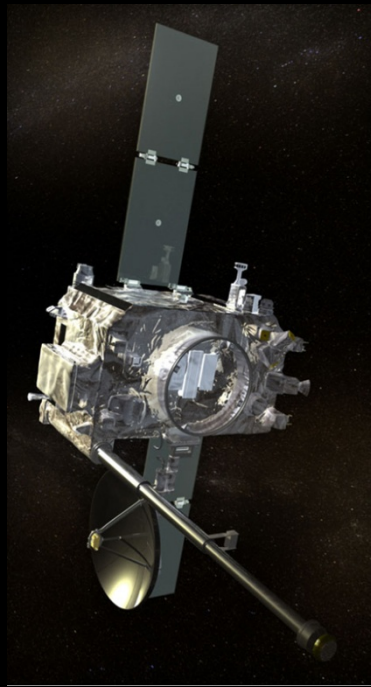


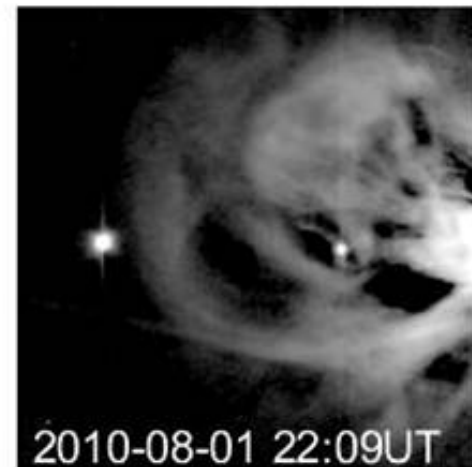
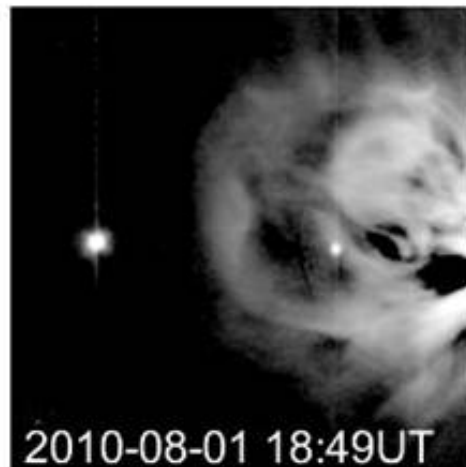
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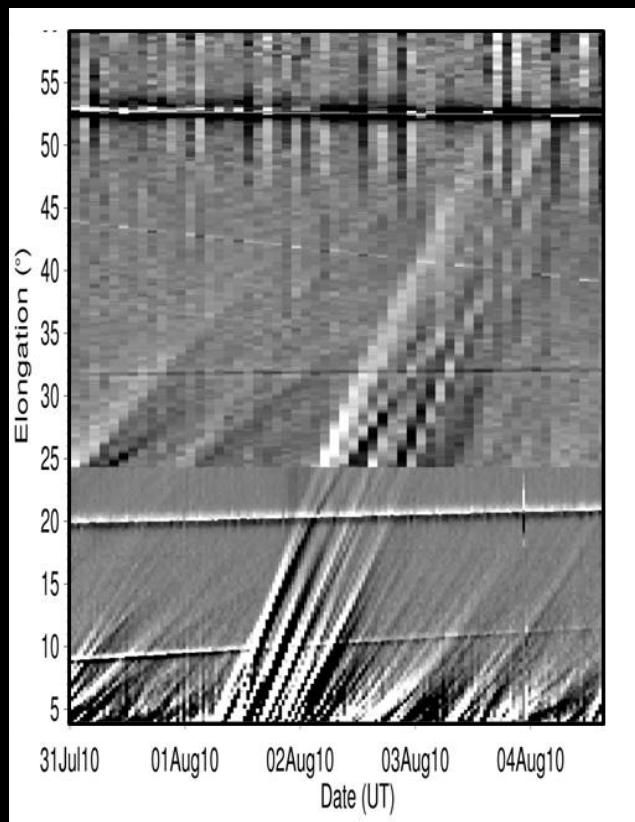
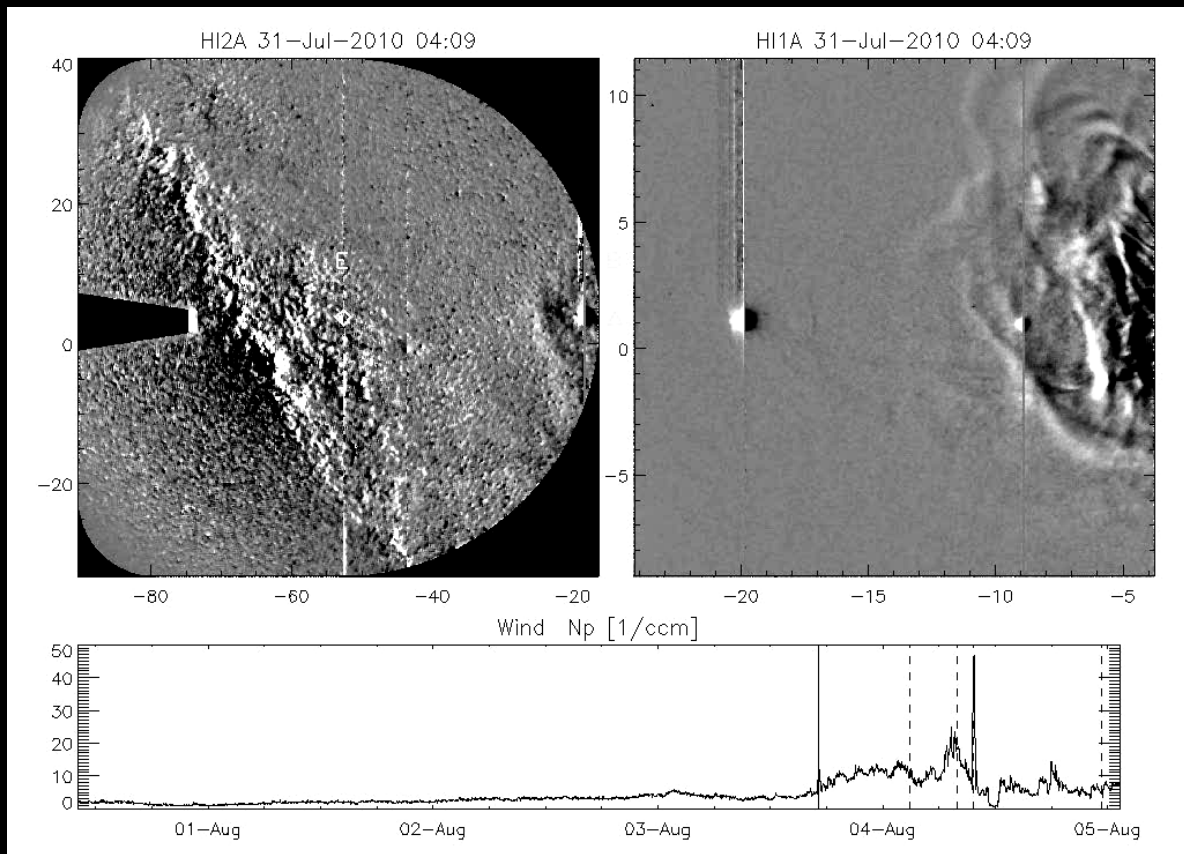


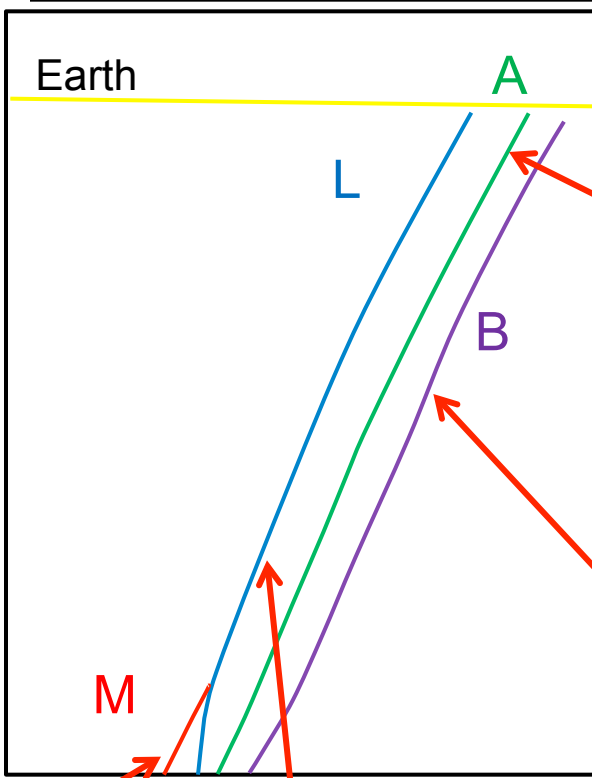
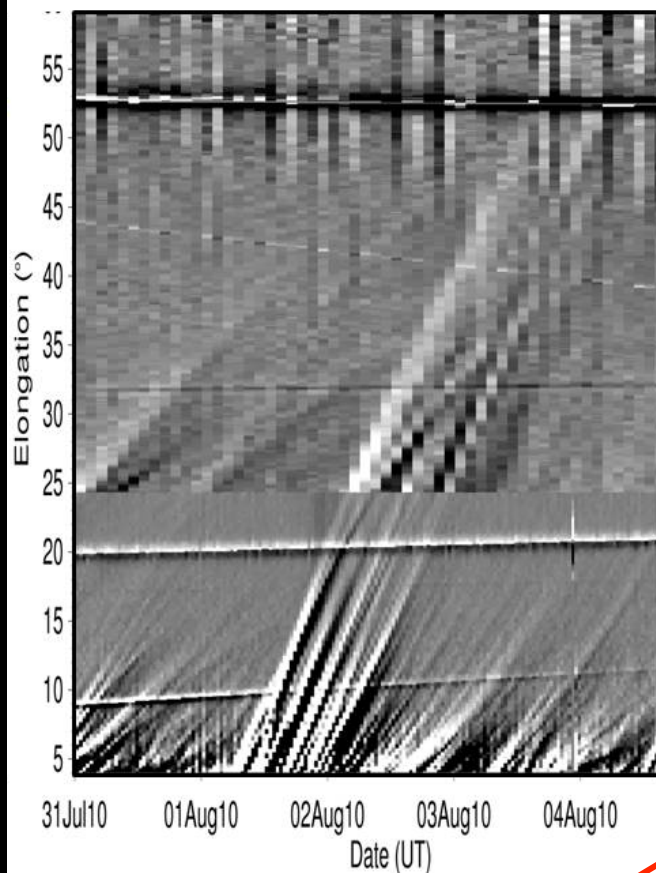
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- Four CMEs in quick succession – the fastest at >1000 km/s
- At least three are Earth-directed





- 600 km/s CME heading towards Earth.
- Onset associated with large filament eruption
- Imaged passing 1 AU - arrival at 06:00 UT on 4 Aug.

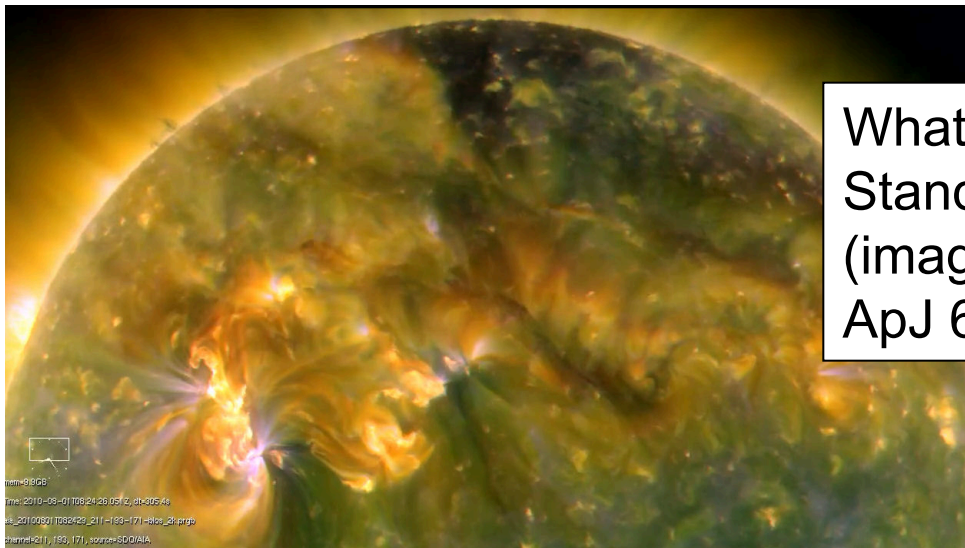
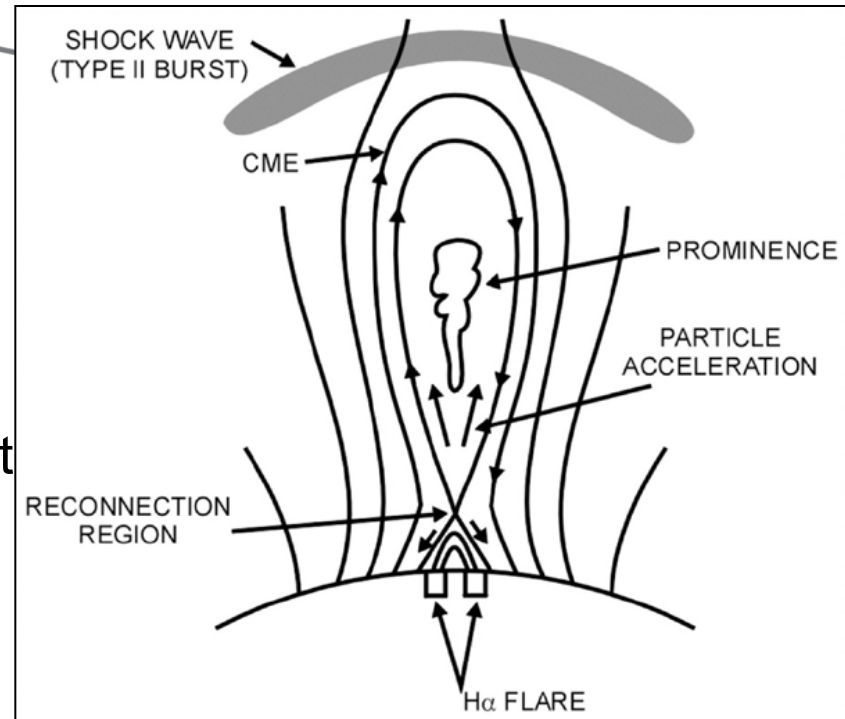
- 585 km/s CME heading 1.5° E of Earth.
- Onset associated with eruption of FI₂ SDO filament
- Imaged passing Earth? - 1 AU arrival mid-a.m. 4 Aug

- 732 km/s
- Heading 15° E to 30° E of Sun-Earth line – overrun by L
- Onset 02:42 UT 1 Aug (consistent with 02:40 UT SDO filament eruption at E10).

- Fast CME (>1200 km/s falling to 600 km/s) heading ~ 0-20° W of Earth.
- Onset consistent with C3 flare
- Consistent with shock at Earth.
- Imaged passing 1 AU - noon on 3 Aug.

3. The flare-CME model

1. Magnetically complex system – includes realistic range of scales
2. Complexity results in flare and or CME driven by magnetic ‘driver’, not each other, and each may or may not occur – depends on local conditions.
3. Note: timing, asymmetry, scales...



What does this all mean for the Standard Flare Model??
(image from Cliver & Ling, 2009, ApJ 690)

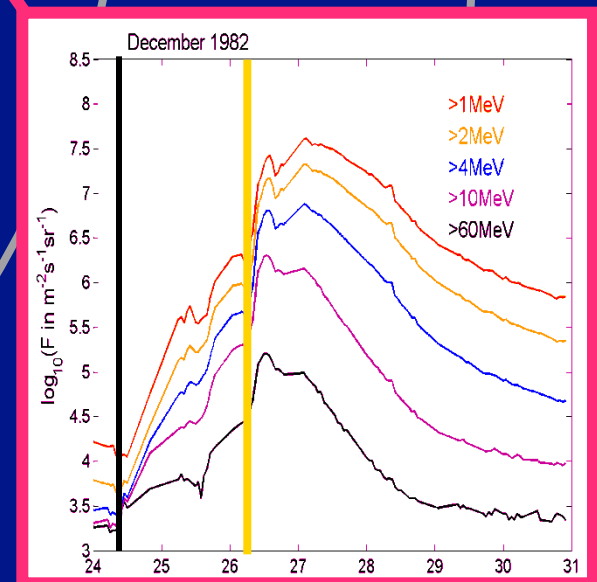
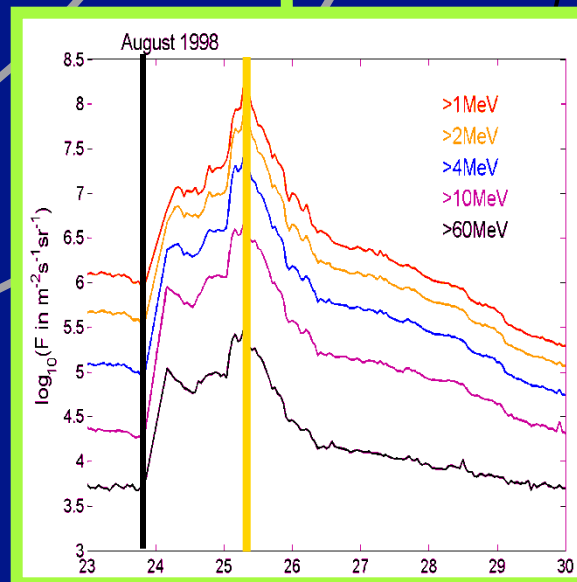
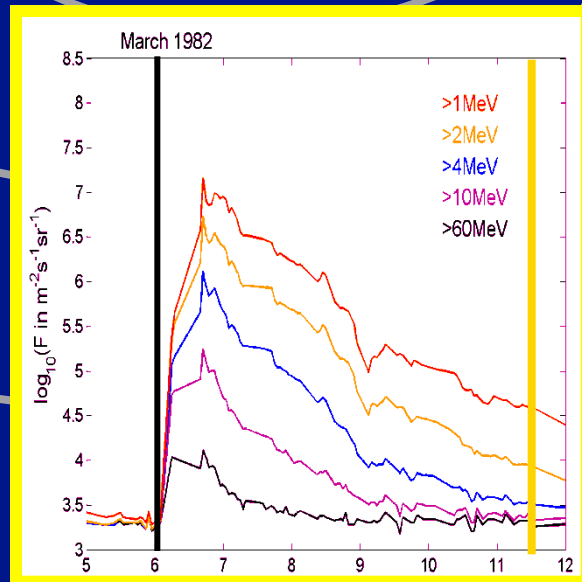
4. Solar Energetic Particle production

- Energetic electrons (~ 1 keV to tens of MeV) & ions (~ 50 MeV per nucleon to ~ 10 GeV) accelerated in association with events initiated at the Sun
- Accelerated in flares (impulsive) or CME shocks (gradual) (note: we also see particles accelerated in CIRs)

	Impulsive	Gradual
Particles	Electron-rich	Proton-rich
Duration	Hours	Days
Longitude Cone	$< 30^\circ$	$\sim 180^\circ$

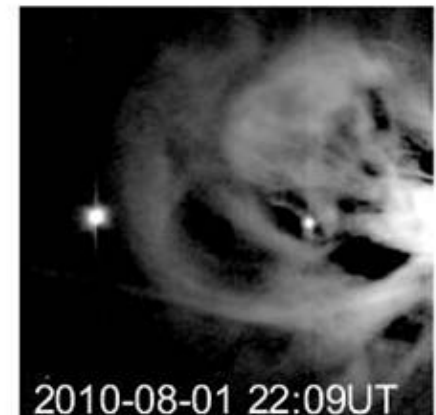
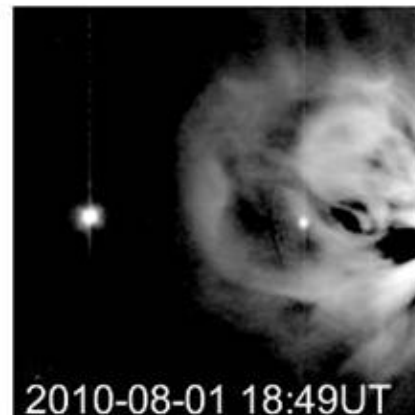
From: Reames, 1997, AGU Geophys. Monograph 99

SEPs produced in both directions by CME shock front (Lockwood, adapted from Reames)



So, what don't we know? What are the issues? (part 1)

- Why are we **still** arguing about the flare-CME relationship? Time we sorted that one out!
- Is the Standard Flare model really still alive?
- Are our tracking/prediction techniques becoming mature enough?
 - To understand onset processes
 - To project arrivals at Earth or elsewhere
 - To understand how Earth cuts through the CME structure and pin down the CME speed (both relevant to expected SEP environment)
 - To understand the geometry (the link to any flare site, and the CME)

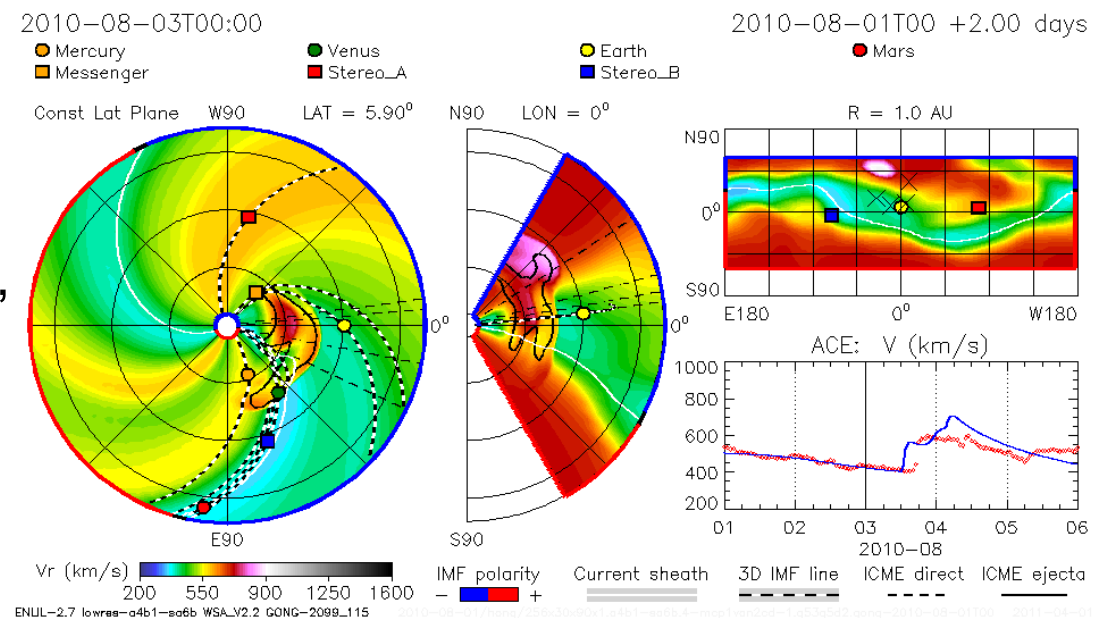


So, what don't we know? What are the issues? (part 2)

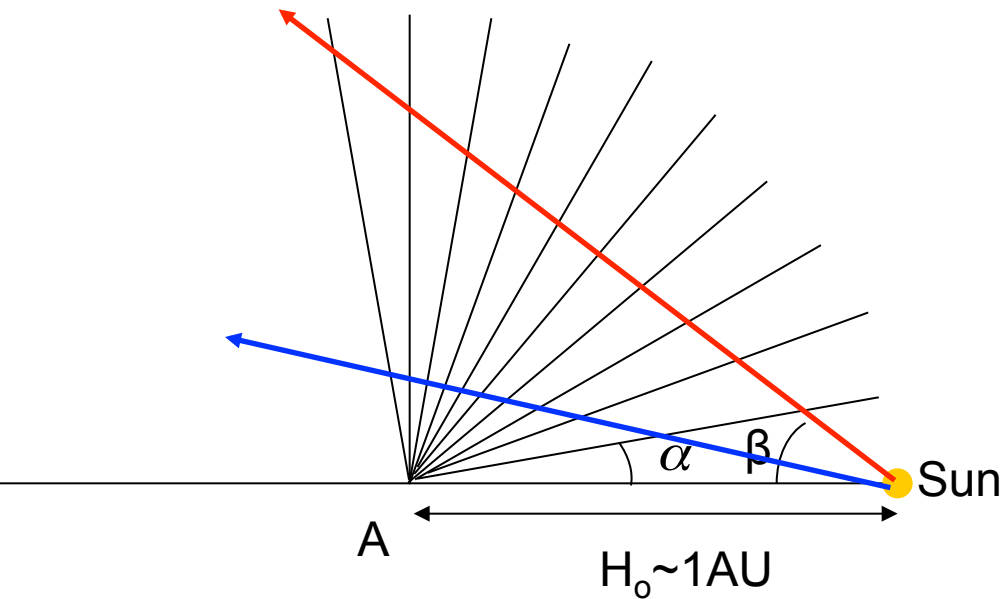
- What about SEP production and the complex structure of the CME?
- What about SEPs and CME-CME interactions?
- Heliospheric modelling – key issue for many recent studies boils

down to the inputs to Enlil (MHD heliospheric model)

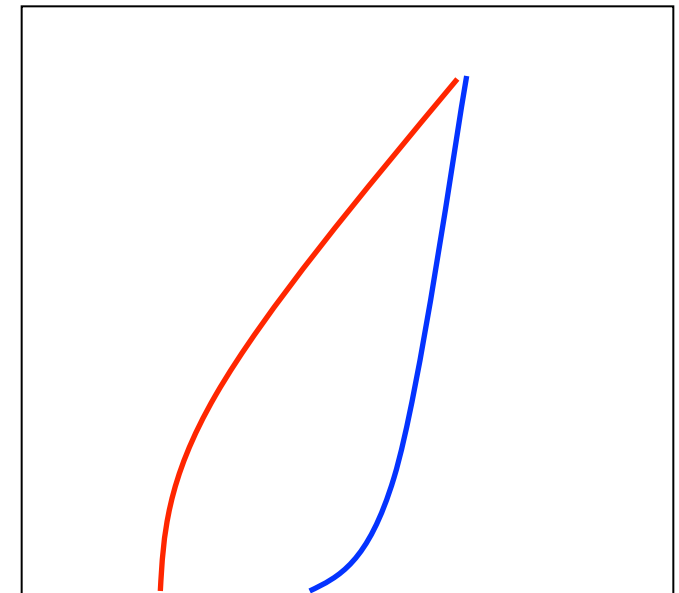
- The pre-event heliosphere
- The CME directions, speeds and sizes
- Shock development in the models



Apparent Acceleration at large elongations



Elongation angle



Time

Assuming the CME propagates radially at a constant speed;

$$\alpha(t) = \arctan \left[\frac{vt \sin(\beta)}{H_o - vt \cos(\beta)} \right] \quad (\text{Sheeley et al., JGR, 1999})$$

